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ABSTRACT

The Water Aerosol Lidar (WALI) system, deployed for 14 weeks during 2012 & 2013 on the island of Menorca, provided the Hydrological cycle in the Mediterranean eXperiment (HyMeX) with an opportunity to perform a multi-platform comparison on moisture retrievals at the timescales relevant for extreme precipitation events in the West Mediterranean basin. After calibration, the WALI lidar yields night-time profiles of water vapor with ~7% accuracy from the ground up to 7 km, and daytime coverage of the lower layers, alongside common aerosol retrievals. It is used to characterize the water vapor profile product given by the IASI instrument on-board MetOp-B, and the fields simulated by the Météo-France AROME-WMED model and the open-source WRF model. IASI is found to be reliable above 1 km altitude, and the two models obtain similar high scores in the middle troposphere; WRF beneficiates from a more accurate modelling of the planetary boundary layer.

1. INTRODUCTION

Because of high orography and intense sea evaporation, the western Mediterranean coastline concentrates major weather hazards. Heavy precipitation and flash-flooding, occurring mainly in the fall, can cause extreme events such as the Gard disaster in France (700 mm daily precipitation in Sep. 2002 [1]). An hourly characterization of water vapor variability across the Mediterranean basin is essential to elucidate the life-cycle of high impact weather systems and improve forecasts of numerical weather prediction (NWP) models. The dedicated Hydrological cycle in the Mediterranean eXperiment (HyMeX), conducted in 2012, opened the opportunity for a multi-instrument (lidar, satellites, balloons…), multi-model comparison to properly apprehend the water vapor variability at the relevant timescales.

The Water vapor Aerosol Lidar (WALI) system developed by LSCE [2] was deployed in Sep.-Nov. 2012 and June-July 2013 on the island of Menorca (shown on Fig. 1). The lidar was embedded in LSCE's Mobile Atmospheric Station (MAS) laboratory van. Its aim during HyMeX was to provide WVMR profiles during the intense observation periods preceding forecasts of extreme precipitation events in Spain and France, to investigate the reliability of moisture fields given by state-of-the-art NWP models and remote sensing instruments.

In this paper, after a description of the instruments and models involved, we present the results of the lidar calibration and validation, and proceed to study the accuracy of high resolution water vapor products by the AROME-WMED and WRF NWP models, as well as the IASI spectrometer on board ESA's MetOp satellite.

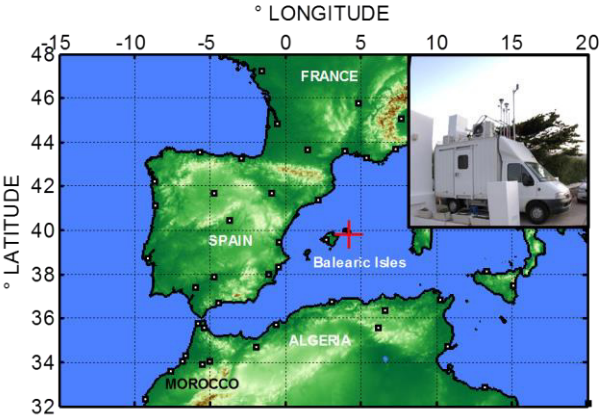

Figure 1. Location of the WALI lidar on Menorca Island near the center of the western Mediterranean, and image of the MAS laboratory van in which WALI is embedded.

2. INSTRUMENTS AND MODELS

The WALI is a transportable and modular lidar instrument dedicated to atmospheric research activities [2,3]. Emitting at 354.7 nm wavelength, it is designed to fulfill eye safety conditions. Its emitter is a pulsed Nd:YAG (Quantel Brilliant) laser, with ~60 mJ UV pulse energy and 20 Hz pulse repetition frequency. Its wide field-of-view ensures a full-overlap of the transmission and reception paths beyond 150 to 200 m. Its characteristics are summarized in Table 1.

Using analog and photon count detection merging, and variable photomultiplier gain as permitted by skylightcontrolled high voltage values, the dynamic range of the receiver is sufficient to allow both nighttime measurements up to ~7 km altitude, and daytime measurements up to 1 km altitude.

Table 1. Characteristics of the mobile WALI Raman lidar.

Laser	**Nd:YAG (freq.tripled)**
Energy	60 mJ at 355 nm
Frequency	20 Hz
Reception channels	Elastic // 355 nm Elastic ⊥355 nm Raman-N_2 387 nm Raman-H_2O 407 nm
Reception diameters	3 x 150 mm
Field of view	2.3 mrad
Full overlap	~200 m
Detector	Photomultiplier tubes
Filter bandwidth	0.2 nm @355&387 nm 0.3 nm @407 nm
Vertical sampling	1.5 m (analog) 15 m (photon counting)
Vertical resolution	~30 m
Acquisition system	PXi techno. at 200 MHz
Lidar head size	~ 90x60x18 cm^3
Total weight	150 kg

In this work, we use lidar measurements from Ciutadella de Menorca (40°01′N, 3°49′E) and Cap d'en Font (39°50′N, 4°12′E) to qualify the moisture fields provided by a space-borne instrument (MetOp/IASI), as well as two high-resolution NWP models (AROME-WMED & WRF):

- The IASI spectrometer [4] was launched in 2012 onboard the polar orbiting meteorological satellite MetOp-B (Operational Meteorology), which forms the space segment of the overall EUMETSAT Polar System. In particular, low resolution vertical profiles of WVMR are retrieved from infrared radiances at the global scale [5]. Here, we use the IASI-derived WVMR operational Level-2 products available via EUMETSAT. It was only validated punctually against radiosoundings and models before, and not in the low troposphere [6].
- AROME-WMED [7] is a dedicated high resolution (2.5 km) operational modelling system covering the western Mediterranean, based on an extension of the adiabatic equations of the ALADIN NWP System [8]. For the HyMeX program it has been run by Météo-France in real-time from Sep. 2012 to March 2013. The data has been horizontally interpolated at the Menorca site, on the 60 model hybrid levels. We use 3-hourly operational analysis, as well as hourly 48-h forecasts.
- We have specifically run the open-source regional non-hydrostatic Weather Research and Forecasting (WRF) model (version 3.5, [9]) for simulations in Sep. and Oct. 2012. Boundary conditions are taken from the 1°×1° Final Global Analysis. Nudging has been applied every 6 hours to wind, temperature and humidity, above the planetary boundary layer (PBL). The horizontal resolution is set to 10 km, and there are 50 pressure levels along the vertical column. Specific models represent land surface, PBL, surface layer, microphysics, subgrid-scale convective, shortwave and longwave radiation schemes.

3. LIDAR CALIBRATION

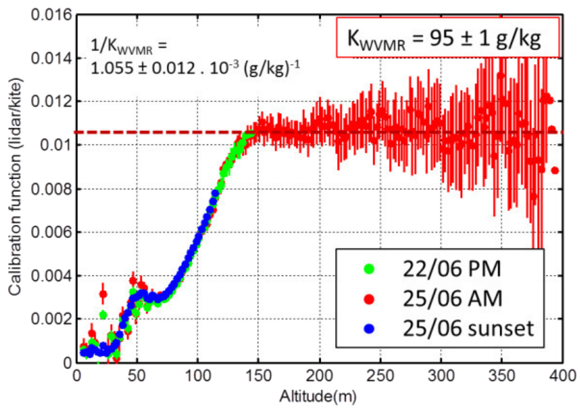

Figure 2. Lidar calibration function as estimated by simultaneous co-located kite-borne water vapor measurements (ratio of lidar/kite WVMRs).

The WVMR is proportional to the ratio between the received signals at 407 nm (water vapor) and 387 nm (nitrogen). The lidar signals are corrected from the differential absorption of the atmosphere at these wavelengths. The coefficient of proportionality, comprising the system constant of the channels and their overlap factors, has to be carefully calibrated. Numerous methods have been proposed to perform this calibration [10,11], but comparison to co-located sounding on site is preferable in the case of a mobile lidar with separate channels. This ensures more precise measurements in the lower troposphere by minimizing the calibration bias.

For both deployments of the WALI lidar, a Vaisala sonde measuring pressure, temperature and relative humidity was flown in the near vicinity of the laser beam, either by plane or by kite directly from the lidar site. In the latter case, a very precise assessment of the calibration function (<2% uncertainty) was possible down to the ground, as shown in Fig. 2, during 3 separate flights of the kite.

To validate the calibration and the daytime WVMR retrieval, Figure 3 shows a daytime inter-comparison between the lidar-derived WVMR, measurements by an airborne sonde and nearby rawindsoundings at Mahon, as well as profiles from the considered meteorological models. In spite of excess noise due to sunlight, WALI's mean uncertainty is below 10% under 1 km during daytime.

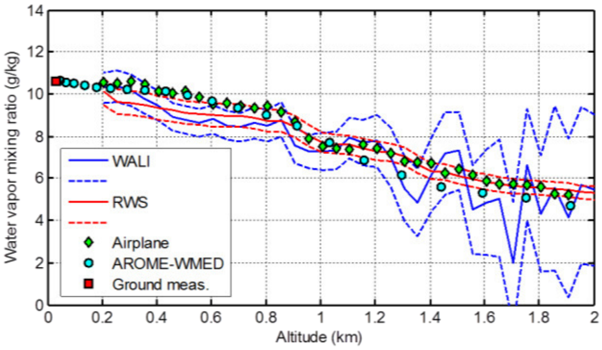

Figure 3. Vertical profiles of WVMR obtained by the calibrated WALI lidar and various measurements (rawindsounding RWS, sonde onboard a plane above the lidar, AROME NWP model) on October 17th, 2013 (daytime, explaining the strong noise on WALI). Dashed lines represent standard deviations.

4. WVMR RETRIEVALS

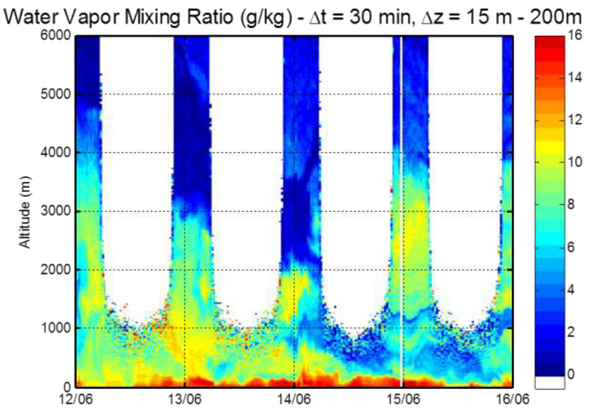

Figure 4. Lidar-derived WVMR from June 12th to June 16th 2013, showing the daytime range limit and the strong variability of atmospheric moisture below 4 km altitude.

In Fig. 4, we show time-altitude cross-sections of WVMR as retrieved by the WALI lidar. The lower profile between the ground and 90 m (first retrievable signal) is completed by a humidity sonde on the lidar van, allowing the observation of the full PBL. The maximum range of the lidar retrieval is artificially limited to Raman signal-to-noise ratios above 5, highlighting the daytime range limit (due to sunlight). During night-time, the accuracy of the WVMR retrieval is around 7% at 5 km [2].

Fig. 4 also highlights a dry layer, from 2 to 6 km altitude on June 12th & 13th, coming from the north Atlantic, as well as three wet plumes, coming from Spain, which have been identified as polluted airmasses using both their optical properties and back-trajectories. This situation is a good example of the great variability of tropospheric water vapor in the region.

5. INTER-COMPARISONS

30 night-time coincidences have been identified across the two campaigns between MetOp-B/IASI and the WALI at Menorca. The Correlation (COR) profile of IASI versus WALI over these cases is plotted in Fig. 5.

Overall, we find a good agreement (COR > 0.75), but only above 1.5 km altitude. By studying individual cases, we find that the remaining deviation is almost always due to strong variability of WVMR with altitude (sharp transitions between wet/dry layers). The weight function of IASI, badly resolved in the low troposphere, is responsible for these errors. Nevertheless integrated water contents provided by IASI are highly reliable [3].

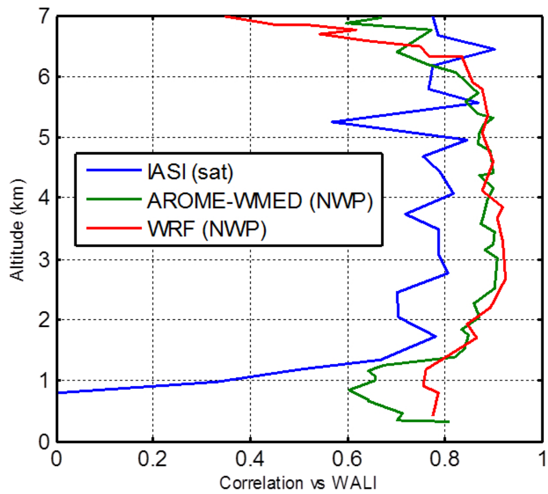

Figure 5. Profiles of correlation scores between the IASI (satellite) WVMR retrievals (blue) and WVRM profiles from the NWP models (AROME, green and WRF, red), versus measurements by the WALI lidar, as a function of altitude.

Also plotted on Fig. 5 are the correlation scores of NWP models AROME-WMED and WRF, compared to WALI over Sep. and Oct. 2012. They are equivalently very good between 2 and 6 km altitude (COR > 0.85), but WRF is better in the PBL thanks to its specific planetary boundary layer scheme. It fares worse in the higher layers due to an underestimation of moisture, which origin remains to be investigated.

6. CONCLUSION

The WALI system, developed by LSCE and deployed for 14 weeks during 2012 & 2013 on the island of Menorca provided the HyMeX program. It was an opportunity to validate the capacity of space-borne instruments and numerical weather models to apprehend moisture variability at the relevant timescales for extreme precipitation events in the West Mediterranean basin. After in-situ calibration, the WALI lidar yielded night-time profiles of water vapor with ~7% accuracy from the ground up to 7 km, and daytime coverage of the lower layers, alongside common aerosol retrievals (extinction, depolarization, lidar ratio…).

WALI was used to characterize the water vapor profile product given by the IASI instrument on-board MetOp-B, and the fields simulated by the Météo-France AROME-WMED model and the open-source WRF model. IASI is found to be quantitatively reliable at low resolution above 1 km altitude, and the two models obtain similarly high scores in the middle troposphere; WRF beneficiates from a more accurate modelling of the moisture trapped in the planetary boundary layer.

Future works within HyMeX will study the accuracy of AROME-WMED forecasts and their potential improvement by the assimilation of lidar data.

ACKNOWLEDGEMENT

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